Technical Report

ESTCP Munitions Response Live Site Demonstrations - Andersen Air Force Base, Guam

ESTCP Project MR-201231

April 2016

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ESTCP MUNITIONS RESPONSE LIVE SITE DEMONSTRATIONS

Andersen Air Force Base, Guam
Demonstration Report

ESTCP Project Number MR-201231
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14. ABSTRACT

This report details a live site demonstration project conducted by WESTON at Andersen Air Force Base, Guam as part of Environmental Security Technology Certification Program (ESTCP) Munitions Response Project MR-201231. The purpose of the project was to demonstrate the effectiveness of the advanced sensor and classification methodology for identifying targets of interest (TOIs) at a military construction (MILCON) site potentially containing a diversity of munitions. A total of 2.97 acres of dynamic detection surveys were conducted using TEMTADS 2x2 advanced electromagnetic induction (EMI) sensor. A total of 1,195 anomalies were selected from the dynamic data for cued investigation. The classification methodology resulted in the correct classification of 100% of TOI and yielded a reduction in clutter digs of 81%.

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LIST OF ACRONYMS

%	percent
AFB	Air Force Base
cm	centimeter
DGM	digital geophysical mapping
DSB	Defense Science Board
EMI	electromagnetic induction
ESTCP	Environmental Security Technology Certification Program
GPS	global positioning system
IDA	Institute for Defense Analysis
IMU	inertial measurement unit
ISO	Industry Standard Object
IVS	instrument verification strip
MEC	munitions and explosives of concern
MILCON	military construction
mm	millimeter
MMRP	Military Munitions Response Program
MRS	Munitions Response Site
mV	millivolt
mV/A	millivolt per amp
NRP	North Ramp Parking
RMS	root mean square
ROC	receiver operating characteristic
RTK	Real Time Kinematic
QC	quality control
SERDP	Strategic Environmental Research and Development Program
TEMTADS	Time-domain Electromagnetic Multi-sensor Towed Array Detection System
TOI	target of interest
UXO	unexploded ordnance
WESTON®	Weston Solutions, Inc.
WWII	World War II

EXECUTIVE SUMMARY

Weston Solutions, Inc. (WESTON®) performed an Environmental Security Technology Certification Program (ESTCP) Live Site Demonstration using a Time-domain Electromagnetic Multi-sensor Towed Array Detection System (TEMTADS 2x2) at the North Ramp Parking (NRP) area, Andersen Air Force Base, Guam. The demonstration was integrated with an ongoing munitions and explosives of concern (MEC) removal action project being performed in advance of military construction (MILCON) activities. Dynamic detection surveys using TEMTADS 2x2 were performed across 2.97 acres of the NRP area following a traditional EM61-MK2 survey. A total of 970 anomalies were selected from the TEMTADS 2x2 dynamic survey data. An additional 225 anomalies were selected from EM61-MK2 data that did not overlap with the TEMTADS 2x2 survey. Each of the 1,195 anomalies were reacquired and interrogated using cued data collection with the TEMTADS 2x2. All targets of interest (TOI) were correctly identified during the demonstration. The classification process resulted in correctly identifying 100% of targets of interest (TOI) and reduced the number of clutter or non-munitions related material that would require investigation by 81%.

1. INTRODUCTION

This is one of a series of Environmental Security Technology Certification Program (ESTCP) demonstrations of classification technologies for munitions response. This demonstration is designed to evaluate the classification methodology at a site with a diversity of munitions types (20 millimeter (mm) to 100-lb bombs). The Time-domain Electromagnetic Multi-sensor Towed Array Detection System (TEMTADS 2x2) was demonstrated at Andersen Air Force Base (AFB), Guam in both dynamic and cued mode by Weston Solutions, Inc. (WESTON®).

1.1 BACKGROUND

The Military Munitions Response Program (MMRP) is constrained by available resources. Remediation of the entire inventory using current practices is cost prohibitive within current and anticipated funding levels. With current planning, estimated completion dates for munitions response on many sites are decades away. The Defense Science Board (DSB) observed in its 2003 report that significant cost savings could be realized if successful classification and differentiation between munitions and other sources of anomalies could be implemented. If these savings were realized, the limited resources of the MMRP could be used to accelerate the remediation of Munitions Response Sites (MRSs) that are currently forecast to be untouched for decades.

To build on the success of previous studies and address resource issues, ESTCP funded a demonstration of the TEMTADS 2x2 instrument at Andersen AFB. This site was selected as a demonstration site because it contains a wide range of World War II (WWII)-related targets of interest (TOIs). The site is also undergoing a munitions and explosives of concern (MEC) removal action in advance of military construction (MILCON) activities.

1.2 OBJECTIVE OF THE DEMONSTRATION

The overall objective of the demonstration was to validate classification technology at the North Ramp Parking (NRP) area at Andersen AFB. The NRP area was undergoing an active MEC removal action in advance of MILCON activities. The advanced geophysical classification activities were integrated with the ongoing removal action. WESTON performed the following tasks to achieve this overall objective:

- Installed an instrument verification strip (IVS) adjacent to the NRP area.
- Perform a dynamic detection survey using NRL TEMTADS 2x2 in a subset of the NRP area.
- Perform static, cued target interrogation using the TEMTADS 2x2 on anomalies selected from both TEMTADS 2x2 and EM61-MK2 datasets.
- Processed cued geophysical data to correctly classify TOI.

1.3 REGULATORY DRIVERS

The MMRP is charged with characterizing and, where necessary, remediating MRSs. When an MRS is remediated, it is typically mapped with a geophysical system, based on either a magnetometer or an electromagnetic induction (EMI) sensor, and the locations of all detectable signals are excavated. Many of these detections do not correspond to munitions, but rather to harmless metallic objects or geologic features. Field experience indicates that often in excess of 90% of objects excavated during the course of a munitions response are found to be nonhazardous items. Current geophysical technology, as it is traditionally implemented, does not provide a physics-based, quantitative, validated means to discriminate between hazardous munitions and nonhazardous items.

With no information to suggest the origin of the signals, all anomalies are currently treated as though they are intact munitions when they are dug. They are carefully excavated by unexploded ordnance (UXO) technicians using a process that often requires expensive safety measures, such as barriers or exclusion zones. As a result, most of the costs to remediate an MRS are currently spent on excavating targets that pose no threat. If these items could be determined with high confidence to be nonhazardous, some of these expensive measures could be eliminated or the items could be left unexcavated entirely.

2. TECHNOLOGY

This demonstration consisted of dynamic and cued data collection with the TEMTADS 2x2 advanced geophysical sensor system. Analysis of the data were performed using conventional and advanced data processing methods to select anomalies from the advanced sensor dynamic detection data, and then extract features and perform anomaly classification on the advanced sensor cued data.

2.1 TECHNOLOGY DESCRIPTION

2.1.1 TEMTADS 2x2

The TEMTADS 2x2 is an adaptation of the Naval Research Lab’s standard TEMTADS 5x5 element sensor configuration using a smaller 2x2 element array. The TEMTADS 2x2 consists of four 35cm transmit coils with four 8cm tri- axial receiver cubes. The receiver cubes are similar in design to those used in the second-generation Advanced Ordnance Locator and the Geometrics MetalMapper) system with dimensions of 8 cm rather than 10 cm. It is as reliable as the original TEMTADS, but its portability and smaller size enables access to difficult terrain where mobility is limited. The center-to-center distance between the transmit coils is 40 cm yielding an 80 cm x 80 cm array. The array is deployed on a set of wheels resulting in a sensor height of approximately 18 cm.

The transmitter electronics and the data acquisition computer are mounted on the operator backpack, and a GPS antenna and an inertial measurement unit (IMU) are mounted above the center of the TEMTADS 2x2 sensor array. The TEMTADS 2x2 can be operated in two modes; dynamic, or detection mode, and cued mode. Data collection is controlled in dynamic mode using the EM3DAcquire application suite, similar to that used for the Geometrics MetalMapper systems. Custom software written by NRL is used for cued data acquisition. In cued mode, the locations of previously-identified anomalies are reacquired and flagged prior to being cued with the TEMTADS 2x2.

Figure 2-1. TEMTADS 2x2

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The major advantage of the advanced EMI sensor and the UX-Analyze software is that used together they provide the ability to classify anomalies as being either TOI or non-TOI. Conventional DGM sensors (e.g., EM61-MK2) have very limited ability to discriminate between TOI and non-TOI. Other advanced EMI sensors (e.g., Geometrics MetalMapper, Berkeley UXO Discriminator, Man-Portable Vector) have also been successful in Strategic Environmental Research and Development Program (SERDP) and ESTCP-funded classification demonstrations; however, they were not used during this live site demonstration.

The TEMTADS 2x2 is a man-portable sensor, however, the associated components (tablet, heavy backpack and batteries) limit the ability of an operator to collect data without assistance from additional personnel. For this demonstration two personnel were utilized during the data collection; one person to operate/navigate the sensor, and a second to operate the tablet and place navigational aids. The TEMTADS 2x2 sensor is also not ruggedized to withstand inclement weather (light rain, snow, etc.). This proved problematic during this demonstration, as the climate on Guam is hot, humid, with frequent precipitation.

3. PERFORMANCE OBJECTIVES

The performance objectives for this demonstration are summarized in Table 3-1 and Table 3-2.

Table 3-1 lists the performance objectives for all field activities. These apply to all detection and classification work performed in the NRP area. Table 3-2 lists the performance objectives for the advanced classification activities. These objectives apply to all similar work performed using NRP area advanced classification data.

Table 3-1. Performance Objectives for Field Activities

Performance Objective	Metric	Success Criteria
Repeatability of Instrument Verification Strip (IVS) measurements	Amplitude of EM anomaly Measured target locations	Adv. Sensors Survey: Down-track location ±25 cm Adv. Sensors Cued: Library match ≥90% using 3-criterion metric with equal weighting to the three criteria using first day's IVS inversion as the library item.
Complete coverage of the demonstration site	Footprint coverage calculated using UX-Process Footprint Coverage Quality Control (QC) tool; excludes inaccessible areas.	>= 85% coverage at 0.50-m line spacing; and >= 98% coverage at 0.60-m line spacing
Along-line measurement spacing	Point-to-point spacing from data set	98% < 25-cm along-line spacing
Detection of all TOI	Percent detected of TOI	100% of TOI detected within 40-cm halo of the surveyed location
Cued interrogation of anomalies	Instrument position	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location

Table 3-2. Performance Objectives for Advanced Classification Activities

Performance Objective	Items	Metric	Success Criteria
Correctly classify QC seeds and correctly classify native and population seed items	All seeds and all native TOI	Percent classified as TOI	100% classified as TOI
Correctly identify group	All TOI and all excavated non-TOI	Percent of TOI and excavated non-TOI grouped correctly	85% correctly grouped in the small, medium, and large groups
Correct estimation of extrinsic target parameters	All excavated anomalies	Measured location and depth to center of mass of recovered items	X, Y < 15 cm (1 σ) Z < 10 cm (1 σ)
Maximize correct classification of non-TOI	All non-TOI	Number of false alarms eliminated	Reduction of clutter digs by >50% while meeting all other demonstration objectives
Minimize number of anomalies that cannot be analyzed	All cued anomalies	Number of anomalies that must be classified as “Unable to Analyze”	Reliable target parameters can be estimated for > 95% of anomalies on each sensor anomaly list.

3.1 OBJECTIVE: REPEATABILITY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS

The reliability of the survey data depends on the proper functioning of the survey equipment. This objective concerns the twice-daily confirmation of sensor system performance.

3.1.1 Metric

The metrics for this objective are the down-track position of the maxima for the TEMTADS 2x2 when used in dynamic survey mode, and the percent match of the inverted data to the library for the specific seed items when surveying in cued mode. These metrics are applied for each of the twice-daily surveys of the IVS.

3.1.2 Data Requirements

The IVS data were used to judge this objective. For cued surveys, the first day’s IVS measurement over each Industry Standard Object (ISO) was used as the library basis for all future IVS comparisons during the project.

3.1.3 Success Criteria

This objective is considered a success for dynamic survey data if the down-track position of the anomaly is within 25 cm of the seed item’s known location. The objective is considered to be met in cued mode if the library matches are equal to or greater than 90%.

3.2 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

The reliability of the survey data depends on the extent of coverage of the site. This objective concerns the ability of WESTON to completely survey the site and obtain valid TEMTADS 2x2.

3.2.1 Metric

The metric for this objective is the footprint coverage as measured by the UX-Process Footprint Coverage QC tool.

3.2.2 Data Requirements

A mapped data file was used to judge the success of this objective.

3.2.3 Success Criteria

This objective is considered a success if the TEMTADS 2x2 dynamic survey achieved at least 85% coverage at 0.5-m line spacing and 98% at 0.6-m line spacing calculated using the UX-Process Footprint Coverage QC tool.

3.3 OBJECTIVE: ALONG-LINE MEASUREMENT SPACING

The reliability of the survey data depends on the measurement density. This objective concerns the ability of WESTON to acquire sufficiently dense measurements to obtain valid data.

3.3.1 Metric

The metric for this objective is the point-to-point distance as measured using UX-Process point-to-point distance tool.

3.3.2 Data Requirements

A mapped data file was used to judge the success of this objective.

3.3.3 Success Criteria

This objective is considered a success for dynamic TEMTADS 2x2 surveys if 98% of the data have along-line spacing of 25 cm or less.

3.4 OBJECTIVE: DETECTION OF ALL TOI

Quality data should lead to a high probability of detecting the TOI at the site. This metric applies only to the detection phases of work and is specific to those items defined as detectable, which for this project is initially defined as peak signal 7 times site root mean square (RMS).

3.4.1 Metric

The metric for this objective is the percentage of seed items that are detected using the specified anomaly selection threshold.

3.4.2 Data Requirements

A target list was generated by WESTON and compared against the surveyed locations of the seed items.

3.4.3 Success Criteria

The objective is considered a success if 100% of the seeded items are detected within a 40-cm halo of their surveyed locations.

3.5 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

The reliability of cued data depends on acceptable instrument positioning during data collection in relation to the actual anomaly location.

3.5.1 Metric

The metric for this objective is the percentage of anomalies that are within the acceptable distance from the center of the instrument to the actual target location during data collection.

3.5.2 Data Requirements

The location of the center of the TEMTADS 2x2 array at each cued anomaly was compared against the measured locations of items recovered during intrusive investigations.

3.5.3 Success Criteria

The objective is considered a success if the center of the instrument is positioned within 40 cm of the actual anomaly location for 100% of the cued anomalies.

3.6 OBJECTIVE: CORRECTLY CLASSIFY QC SEEDS AND CORRECTLY CLASSIFY NATIVE AND POPULATION SEED ITEMS

This metric applies to QC seeds, population seeds, and native TOI. Seed items are used to provide objective and quantitative measurement of the classification process and are used to supplement advanced classification objectives.

The seeds for this demonstration are small ISO80s and 37mm projectiles. The objective for the advanced classification process for this demonstration is to correctly classify 100% of all TOI.

3.6.1 Metric

The metrics for this objective are the percentage of TOI correctly identified on the TOI lists.

3.6.2 Data Requirements

Ranked anomaly lists, separated into TOI and non-TOI lists, were used to judge the success of this objective.

3.6.3 Success Criteria

The objective is considered to be met if 100% of the QC seeds, population seeds, and native TOI are placed on the TOI list.

3.7 OBJECTIVE: CORRECTLY IDENTIFY GROUP

The objective is to correctly assign each TOI and non-TOI to either the small group (small ISO80 and up to 40mm diameter), medium group (medium ISO and up to 81mm diameter), or large group (90mm and 105mm projectiles).

3.7.1 Metric

The metrics for this objective are the percentage of TOI and non-TOI correctly grouped in either the small, medium, or large groups.

3.7.2 Data Requirements

Anomalies grouped as small, medium, or large were used to judge the success of this objective. The data depended on the usability of the beta ($\beta 2$) and $\beta 3$ polarizability curves.

3.7.3 Success Criteria

The group assignment task is considered successful if 85% or more of the group designations are correct.

3.8 OBJECTIVE: CORRECT ESTIMATION OF EXTRINSIC TARGET PARAMETERS

This objective involves the accuracy of the target parameters that are estimated in the first phase of the analysis (data inversion). Successful classification is possible only if the input features are internally consistent. The obvious way to satisfy this condition is to estimate the various target parameters accurately.

3.8.1 Metric

Accuracy of estimation of extrinsic target parameters is the metric for this objective.

3.8.2 Data Requirements

The predicted anomaly locations and depths were compared against the measured locations of items recovered during intrusive investigations.

3.8.3 Success Criteria

The objective is considered a success if the estimated X, Y locations are within 15 cm (1 σ) and the estimated depths (Z) are within 10 cm (1 σ).

3.9 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms, was able to classify the targets with high accuracy. This objective concerns the component of the classification problem that involves false alarm reduction.

Because the number of clutter items that may resemble 20mm projectiles is unknown, the success metric for this objective (50%) is lower than that of most previous demonstrations, which typically use a metric of 65%.

3.9.1 Metric

The metric for this objective is the number of cued anomalies that can be correctly classified as non-TOI.

3.9.2 Data Requirements

WESTON prepared a prioritized non-TOI list from the cued anomaly list. Institute for Defense Analysis (IDA) personnel used their scoring algorithms to assess the results.

3.9.3 Success Criteria

The objective is considered a success if more than 50% of the non-TOI items can be correctly labeled as non-TOI while meeting the objectives or success criteria for TOI stated in Table 3-2.

3.10 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Anomalies for which reliable parameters cannot be estimated cannot be classified by the classifier. These anomalies must be placed in the dig category and will consequently reduce the effectiveness of the classification process.

3.10.1 Metric

The number of anomalies for which reliable parameters cannot be estimated is the metric for this objective.

3.10.2 Data Requirements

Anomalies for which parameters cannot be reliably estimated are assigned a category 0 on the final ranked anomaly list.

3.10.3 Success Criteria

The objective is considered a success if reliable parameters can be estimated for > 95% of the anomalies on each sensor anomaly list.

4. SITE DESCRIPTION

Andersen AFB is a United States Air Force base spanning 20,000 acres in the city of Yigo (pronounced "Geego") on the northern end of the island of Guam. Along with Naval Base Guam, Andersen AFB was placed under the command of Joint Region Marianas on 1 October 2009. Andersen AFB, 36th Wing, Air Mobility Command, opened as North Field in 1944, and was primarily used as a B-29 staging base in the Pacific during WWII. Later it was renamed after Brigadier General James R. Andersen, former Chief of Staff for the Army Air Force, Pacific. The base continues to support strategic operations in the region, and serves as a staging base for activities in Asia and the South Pacific. The bulk of Andersen's duties since WWII have been as a Strategic Air Command base, supporting activities in Korea and Vietnam.

4.1 SITE SELECTION

The Anderson AFB NRP area was chosen as the first geophysical classification demonstration site located in Guam. The NRP area will be undergoing construction activities under the MILCON program. MEC are known or suspected to be present at various sites on Guam as a result of WWII battles and subsequent military activities. MEC are a safety hazard and may constitute an imminent and substantial endangerment to construction personnel and the local population. As a requirement of the MILCON program, sites such as the NRP area that have a moderate to high probability of encountering MEC require a removal action in advance of construction. This demonstration was integrated with a previously scheduled MEC removal action.

The NRP area site provides opportunities to demonstrate the capabilities and limitations of the geophysical classification process on a MILCON project footprint crowed with utilities, previous infrastructure, and potential MEC. Results of the demonstration provide insight and consideration for future use of geophysical classification ahead of MILCON programs and projects. Also, besides the MILCON efforts, there are a number of MMRP sites on Guam that will benefit from the results of this demonstration.

4.2 BRIEF SITE HISTORY

Guam was an American territory in 1941 when the island was invaded by the Japanese military on December 8, 1941. The Japanese military occupation of Guam lasted from 1941 until 1944 when the United States military liberated Guam. The Battle of Guam began on July 21, 1944 with American troops landing on the western side of the island. After several weeks of heavy fighting, Japanese forces officially surrendered on August 10, 1944. The heavy military activity on Guam caused a variety of American and Japanese war time remnants, including MEC, to be distributed throughout the island. The results of the MEC distribution has resulted in the investigation and removal of MEC in a systematic process under the MILCON program.

4.3 MUNITIONS CONTAMINATION

The expected munitions at Andersen AFB NRP area are listed in Table 4-1, which are based on the information in the Explosives Safety Submission (ESS) and the current conceptual site model. The known items in the table identify munitions types recovered by Explosive Ordnance Disposal (EOD) Units between 1991 and 2011 and other suspected items.

Table 4-1. Known and Suspected Munitions Types

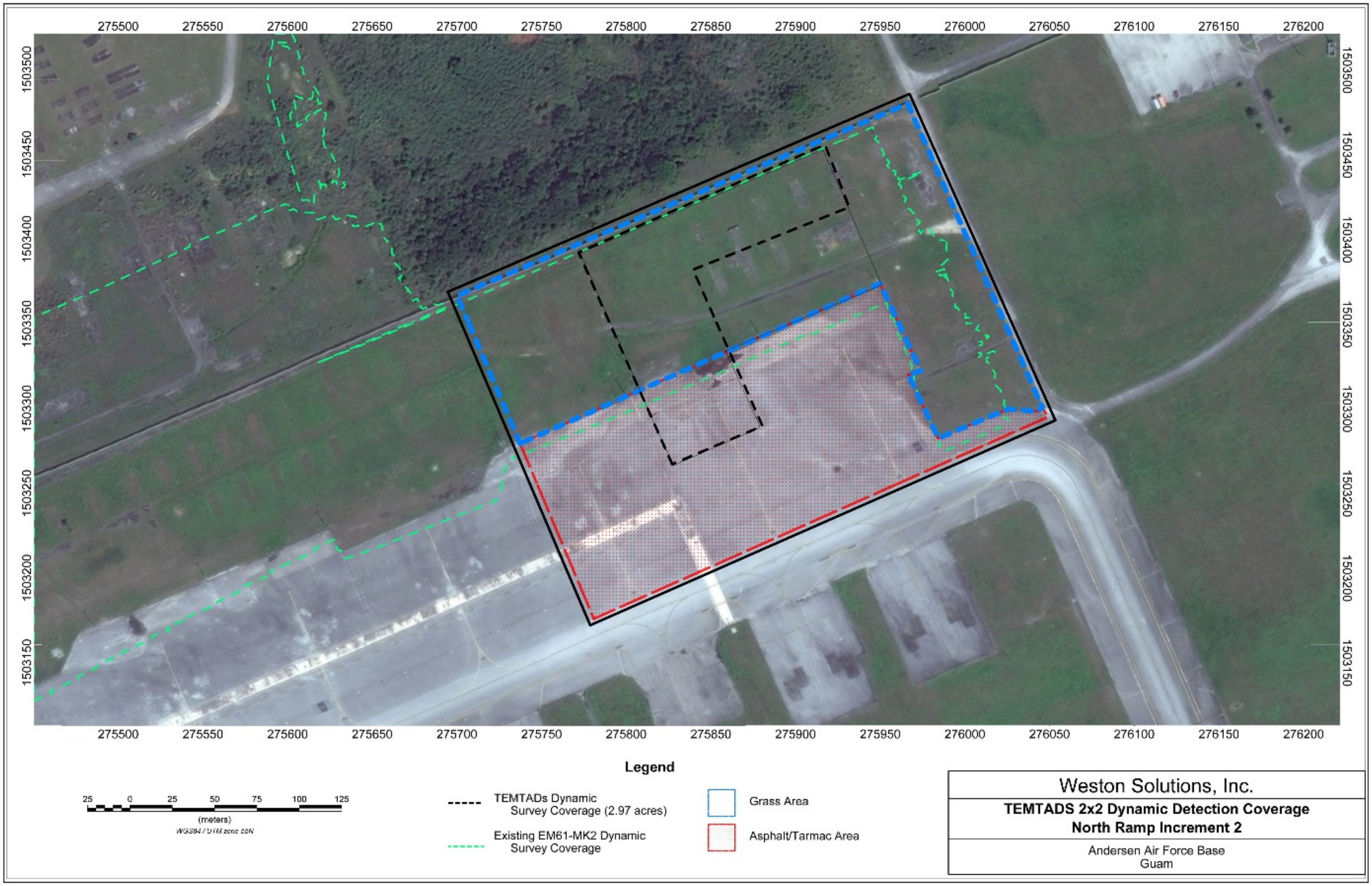
Anderson AFB, NRP Area
MK II Hand Grenades*
20mm mortar
60mm mortar*
81mm mortar*
105mm projectiles*
155mm projectile*
5-inch projectile*
6-inch projectile*
100 lb bomb*

* Items were recovered by EOD Units between 1991 and 2011.

4.4 SITE CONFIGURATION

The demonstration area covers 3 acres within the NRP area. The TEMTADS 2x2 was used in dynamic mode to survey the 3 acre site with 100% coverage. The demonstration site boundaries and surface types are shown in Figure 4-1.

Figure 4-1. NRP TEMTADS 2x2 Demonstration Area



5. TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The objective of this program was to demonstrate a methodology for the use of classification in the munitions response process. The three key components of this methodology were collection of high-quality advanced sensor dynamic detection mapping data; selection of anomalous regions in those data; and subsequent cued interrogation and analysis of the selected anomalies using physics-based models to extract target parameters such as size, shape, and materials properties; and the use of those parameters to construct a ranked anomaly list. Each of these components was handled separately in this program.

Dynamic data were processed, and anomalies were selected and combined with existing EM61-MK2 datasets. Each of the selected anomalies were subsequently cued using the TEMTADS 2x2. Individual cued data sets were processed using existing routines in UX-Analyze Advanced to extract target parameters. These parameters were passed to the classification routines that were used to produce ranked anomaly lists.

A total of 1,195 anomalies in the NRP area were selected for cued interrogation. Intrusive investigation of these anomalies was handled by the contractor performing the removal action.

5.2 SITE PREPARATION

5.2.1 Survey of Historical Records

Much of the historical information on this site has been collected in the ESS. This report is posted on the ESTCP ftp server and can be used for reference.

5.2.2 First-Order Navigation Points

Two first-order survey monuments were installed at the site. Their labels and coordinates are provided in Table 5-1.

Table 5-1. Geodetic Control Locations

ID	Latitude	Longitude	Elevation NAVD88 (m)	Northing (m)	Easting (m)
ESTCP1	N13º35’43.667395	E144º55’49.582789	174.59	1503938.212	276077.554
ESTCP2	N13º35’25.008458	E144º55’25.235422	160.518	1503370.904	275340.62

5.2.3 Initial EMI Survey

Anomaly density information derived from previously collected full coverage EM61-MK2 dynamic survey data was used to define the demonstration site boundaries. The TEMTADS 2x2

demonstration area included a portion in an open grassy area, as well as a portion on the adjacent runway tarmac.

5.2.4 Surface Sweep

The contractor performing the removal action conducted a surface sweep across the demonstration area prior to collecting the dynamic survey data. UXO technicians performed the surface sweep to remove surface metal and any explosive hazards associated with potential MEC.

5.2.5 Seed the Site

WESTON emplaced 36 seed items consisting of inert 37mm projectiles and Small Schedule 80 ISOs within the demonstration area in accordance with the parameters laid out in the *ESTCP MR Live Site Demonstration Seeding Plan.* However, due to time constraints encountered during the dynamic detection survey, only 19 seed items fell within the final 3-acre coverage area surveyed during with the TEMTADS 2x2. During the seeding process, each flagged location was swept with a Schonstedt to ensure a clean area for emplacement. A hole was dug and seeds were placed at the appropriate depth based on seed type, with larger items placed at greater depth. Physical characteristics of the seed were recorded on a whiteboard and placed alongside the excavated hole for a photograph. A Trimble R8 Real Time Kinematic (RTK) GPS was used to measure and record the location of each anomaly at depth.

5.2.6 Establish an IVS and Test Stand

An IVS and test stand area were established within a quiet area free of subsurface metal adjacent to the demonstration site. The IVS was visited twice daily to verify proper sensor operation and functionality. An as-built schematic of the IVS is detailed in Figure 5-2. Details of seed items placed in the IVS are listed in Table 5-2.

Figure 5-1. Layout of the IVS Established at the NRP Area

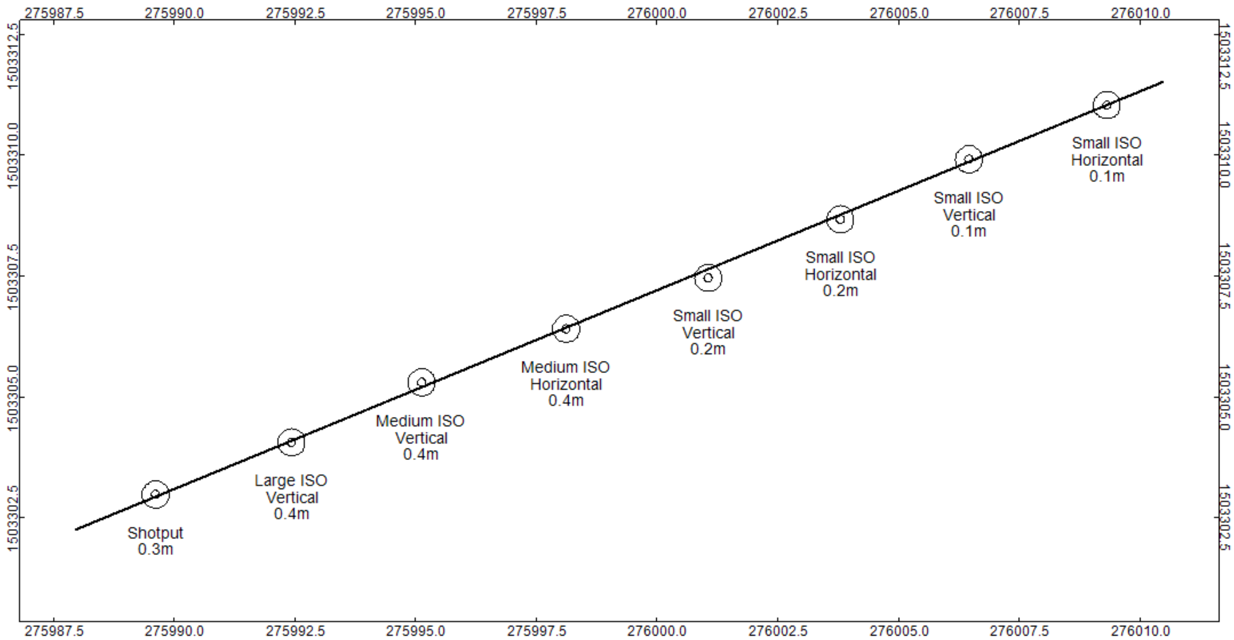


Table 5-2. Details of the Instrument Verification Strip

Item ID	Description	Design Easting (m)	Design Northing (m)	Depth (m)	Inclination	Azimuth
IVS01	Small ISO40	276009.309	1503311.042	0.10	Horizontal	Along-Track
IVS02	Small ISO40	276006.455	1503309.922	0.10	Vertical	N/A
IVS03	Small ISO40	276003.791	1503308.678	0.23	Horizontal	Along-Track
IVS04	Small ISO40	276001.055	1503307.465	0.23	Vertical	N/A
IVS05	Medium ISO	275998.11	1503306.411	0.43	Horizontal	Along-Track
IVS06	Medium ISO	275995.119	1503305.304	0.43	Vertical	N/A
IVS07	Large ISO	275992.423	1503304.063	0.44	Vertical	N/A
IVS08	Shotput	275989.610	1503302.982	0.30	N/A	N/A

Due to limited suitable space available to install a separate IVS within the NRP area, the existing IVS established for the EM61-MK2 survey being performed in support of the MEC removal activities was used for the demonstration. The IVS was modified by adding a shotput. However, the existing seeds, which included Small Schedule 40 ISOs, were left unchanged.

The IVS was used for daily function checks of the survey equipment. WESTON surveyed the strip twice daily, once each morning and evening of survey work, in order to monitor the responses and detected positions of the IVS seed items throughout the duration of the project.

A test stand location was established near the IVS at a quiet location free of subsurface metal and was used to measure the signatures of TOI expected to be present within the demonstration area. The only native TOI available during the demonstration were 20mm and 37mm projectiles, so test stand measurements were limited to those items. Measurements were performed for each test item at multiple depths and orientations. The test stand data collected are listed in Table 5-3.

Table 5-3. Test Stand Items and Orientations

Item ID	Depth (cm)	Orientation
Small ISO80	10, 20	Horizontal, Vertical
20mm	5, 10	Horizontal, Vertical
37mm projectile	10, 15, 20	Horizontal, Vertical

5.3 DATA COLLECTION

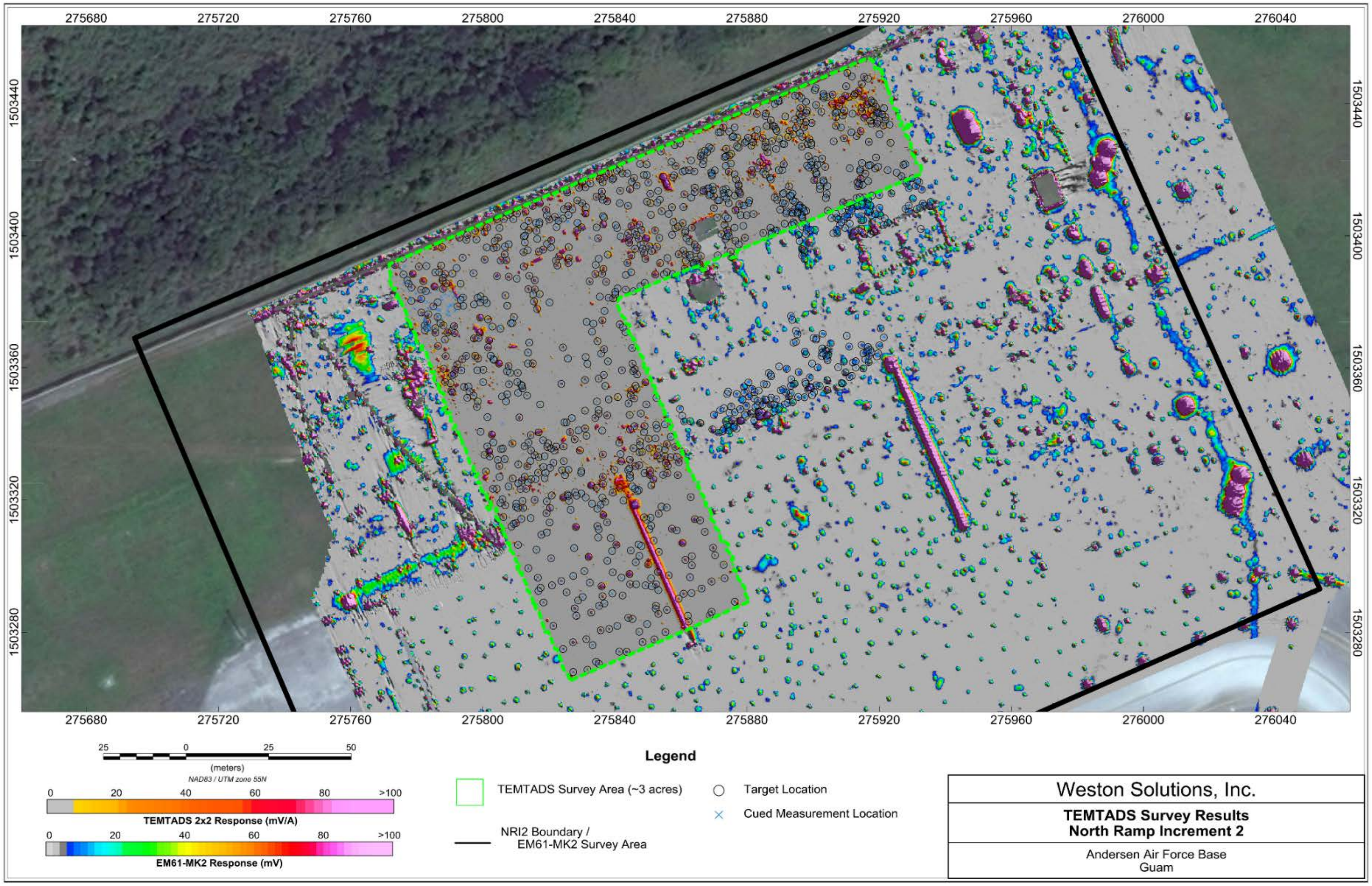
5.3.1 Dynamic Data Collection

WESTON performed dynamic detection surveys with the TEMTADS 2x2 using EM3DAcquire to control data acquisition parameters, storage of data, and real-time monitoring of TEMTADS 2x2 sensor and peripheral IMU and RTK data streams. A Trimble R8 RTK GPS was used for navigation. The rover head was mounted directly over the center of the TEMTADS 2x2 array. An IMU was installed directly below the rover head to capture pitch, roll, and yaw of the sensor. Dynamic TEMTADS 2x2 survey data were acquired with a design line spacing of 0.50 m.

Dynamic detection surveys were conducted over the course of 5 days from January 7 to 17, 2014. There were a number of no-collection days during this timeframe due to inclement weather as well as TEMTADS 2x2 sensor and computer malfunctions. Dynamic detection data were collected over a total of 2.97 acres using the TEMTADS 2x2, equating to an average of 0.6 acres per day of data collection. Data gaps were typically identified in the field and re-collected the same day to ensure full coverage.

Dynamic detection coverage for both the TEMTADS 2x2 and the existing EM61-MK2 dataset is shown in Figure 5-2. The locations of the final targets derived from the TEMTADS 2x2 and EM61-MK2 datasets, as well as the subsequent cued measurement locations for each reacquired target location, are also shown.

Figure 5-2. NRP Area TEMTADS 2x2 and EM61-MK2 Geophysical Survey Coverage



5.3.2 Dynamic Data Processing

The raw binary TEMTADS 2x2 *.TEM files were converted to ASCII *.CSV files using NRL TEMT2CSV data conversion software. Converted data were then imported into Geosoft Oasis montaj for processing and analysis using scripted import routines. Upon import, raw data were inspected to ensure that sensor data were valid and that peripheral input data streams (GPS, IMU) were present and valid. Dynamic detection data were imported, processed, and validated on a daily basis.

Data from each TEMTADS 2x2 sensor were then located using the UX-Analyze Advance "Create Located Database" GX and exported to a separately located database, with each sensor assigned a unique version number per line (e.g. Line 1, sensor 1 equates to Line 1.1, Line 1, sensor 2 equates to Line 1.2). Sensor offsets were calculated in reference to the RTK GPS position at the center of the array, with IMU data used to adjust for pitch, roll, and yaw in the sensor array. Data analysis and anomaly selection were performed on the z-axis component of the four receiver cubes.

The dynamic detection data were then levelled using a de-median background removal filter. Once the daily data had been imported, validated, and levelled, the data were then merged into a master site database containing all dynamic data collected to date. Once data collection was complete, the master database was used for gridding, anomaly selection, and analysis.

5.3.3 Anomaly Selection

Anomalies were selected from processed TEMTADS 2x2 dynamic detection data using the Geosoft Blakely grid peak detection algorithm. To determine a suitable anomaly selection threshold, dynamic test data were acquired over a 20mm projectile placed adjacent to the NRP demonstration area in a horizontal orientation at four depths - 5cm, 10cm, 15cm, and 20cm. At each depth, dynamic TEMTADS measurements were collected along individual passes with the test item oriented both along-track and cross-track. Minimum responses for each 20mm depth are listed in Table 5-4.

Table 5-4. Results of 20mm Dynamic TEMTADS 2x2 Measurements

Item	Depth (cm)	Orientation	Alignment	Peak Response (mV/A) Sum of Gates 5 - 12
20mm	5	Horizontal	Along-Track	17.18
20mm	10	Horizontal	Along-Track	9.98
20mm	15	Horizontal	Along-Track	5.17
20mm	20	Horizontal	Along-Track	4.60

Sub-window statistic calculations were then performed on data from the IVS background strip, as well as at four anomaly free locations within the dynamic TEMTADS 2x2 dataset to assess background noise. RMS noise varied from 0.77mV/A RMS to 1.97mV/A RMS based on location within the NRP area. Data from each area was combined and analyzed, and the results are listed in Table 5-5.

Table 5-5. NRP Area Background Statistics

Minimum Response (mV/A)	Maximum Response (mV/A)	Mean Response (mV/A)	RMS Noise (mV/A)	7xRMS Noise (mV/A)
-6.69	4.34	-0.19	0.99	6.94

RMS noise in anomaly free areas within NRP area were approximately 0.99mV/A for the monoZ_5_12_lev data channel (sum of gates 5 – 12). A threshold of 6.94mV/A (7 times the RMS noise level) was used to allow the selection of a 20mm at a depth of up to 10 cm below ground surface, and potentially deeper, depending on item orientation.

A preliminary target list was generated from the TEMTADS 2x2 dataset based on the 6.94 mV/A threshold. The TEMTADS 2x2 anomaly locations were then compared to the target locations in the existing EM61-MK2 target list to generate a final target list of coincident TEMTADS 2x2 and EM61-MK2 anomalies. The locations for cued reacquisition used the TEMTADS 2x2 target locations in areas with dynamic TEMTADS 2x2 data coverage, and the EM61-MK2 anomaly locations in areas with only EM61-MK2 data coverage. A total of 970 anomalies were selected from the TEMTADS 2x2 dataset. An additional 225 anomalies were selected from the existing EM61-MK2 dataset collected for the MEC removal action.

5.3.4 Cued Data Collection

WESTON performed cued data collection over the course of 10 days between January 18 and February 05, 2014 at 1,195 anomalies that were based on the approved target lists. Cued data collection averaged 120 cued locations each day during the 10 field days. Cued target locations were reacquired with the RTK GPS and flagged each day prior to data collection. The operator then positioned the TEMTADS 2x2 within 40 cm of the center of flagged location and collected a cued measurement over the anomaly. To account for changing background conditions, background measurements were collected once per hour in a quiet area identified in the dynamic data set. The cued data were reviewed each evening, and cued locations that fell outside the 40-cm offset metric were re-collected as necessary.

5.3.5 Cued Data Processing

Cued data processing was performed using the UX-Analyze Advanced extension in Geosoft Oasis montaj. Cued background data were imported and qualitatively verified, with any outliers removed from the background dataset. After background data had been verified, cued anomaly data were imported, verified for completeness, and background corrected using the cued background data spatially and temporally closest to the cued anomaly location.

Inversions were performed on each cued anomaly using both single-source and multi-source models to extract target parameters, fit coherence, and predicted locations and depths for each model. The primary parameters used for classification were the three polarizabilities (β_1, β_2, and β_3) calculated for each single-source and multi-source modeled result.

Daily quality control was performed on the cued anomaly data in which the cued location (Real Time Kinematic [RTK] GPS location), modeled locations, and flagged locations were compared to verify that the center of the TEMTADS 2x2 array was within the 40-cm radius of the anomaly source. Targets outside the 40-cm metric were identified and re-collected as time allowed.

After the individual, inverted locations from the cued sensors were complete, the data were combined into a master dig list for each anomaly group. These Master Dig Lists contained one entry for each predicted anomaly from the inversions of the cued data.

5.3.6 Data Handling

WESTON provided dynamic detection data to the ESTCP Program Office for archiving in raw instrument *.TEM and converted ASCII *.CSV formats, as well as located, processed data in Geosoft database (*.gdb) format. Cued data were provided in raw instrument files *.TEM format, uncorrected ASCII *.CSV files, and background corrected data in Geosoft *.GDB format.

5.4 INTRUSIVE ACTIVITY AND PROCEDURES

Intrusive investigation was performed by the 3rd-party contractor performing the MEC removal action and construction support work at the NRP area MILCON project. Intrusive procedures were performed to the specifications of the 3rd-party contractor's work plan, and did not follow the standard ESTCP intrusive investigation requirements, so dig data obtained did not include precise locations, depths, nor descriptions.

6. CLASSIFICATION

Classification for cued anomaly data collected at the NRP Area was based primarily on the library match statistic generated in UX-Analyze Advanced during library matching of modeled results against the demonstration site TOI library of expected munitions and TOI. The multi-criteria method (introduced in UX-Analyze v8.2) was used, in which the library match statistic of four combinations of beta (β) criteria weights were calculated and then averaged to create a decision statistic. Library match statistic combinations used to calculate the decision statistic are listed in Table 6-1.

Table 6-1. Multi-Criteria Library Match Statistic Combinations

Library Match Statistic Combination	Criteria Weighting		
	β1	β2	β3
LmStat_111	1	1	1
LmStat_110	1	1	0
LmStat_011	0	1	1
LmStat_100	1	0	0

In addition to the matching of βs to a library of known TOI, self-matching was also performed in which βs for each modeled result were compared to the βs of all other modeled results to identify clusters of similar items that may not be present in the TOI library. Items identified in self-match clusters or from clusters identified in feature space (size vs decay plot) were then evaluated to be included in a training data request. Cluster analysis resulted in a training data request for 13 digs. The data received from the training digs were used to further refine the decision metric thresholds in the ranked anomaly list. Clutter items from the training dig results were also added to the clutter library to be used in the final classification process.

The following parameters were used in the ordering of the ranked anomaly list:

- Decision statistic
- Signal amplitude
- Fit depth
- Size and decay
- Array to fit location offset
- Fit coherence
- Library match statistic to clutter library

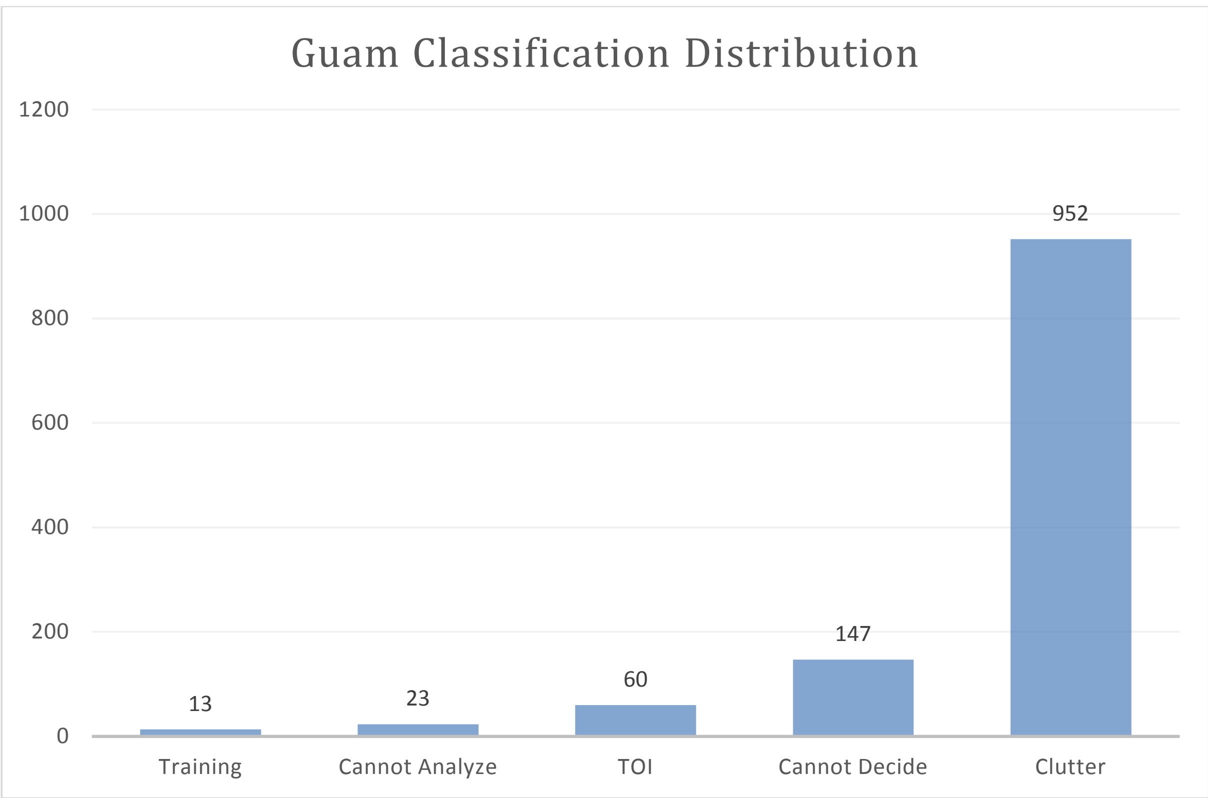
From these parameters, each single and multi-source modeled result was placed into one of four categories 0 to 3, with the best ranked modeled result from each cued anomaly being passed onto to a final ranked list based on the parameters outlined in Table 6-2.

Table 6-2. Ranked List of Parameters

Ranked List Category	Category Description	Criteria
Category -1	Training Digs	Training digs requested by analyst
Category 0	Cannot Analyze	Fit coherence < 0.8
Category 1	Likely TOI	Decision statistic >0.90
Category 2	Cannot Decide	Decision statistic >0.85 but <0.90
Category 3	Clutter	Decision statistic <0.85

The ranked anomaly list derived from this classification scheme resulted in the classification distribution displayed in Figure 6-1.

Figure 6-1. NRP Area Classification Distribution



WESTON submitted the ranked anomaly list to the ESTCP Program Office for scoring by the IDA. The intrusive results, including anomaly descriptions, and a receiver operating characteristic (ROC) curve indicating the percentage of TOI identified for the 243 anomalies placed on the dig list (Categories 0, 1, and 2), were supplied to WESTON for review.

7. PERFORMANCE ASSESSMENT

The performance objectives for this demonstration and the corresponding results are summarized in Table 7-1 and Table 7-2.

Table 7-1 lists the performance objectives for the field activities. These apply to the detection and classification work performed at NRP Area. Table 7-2 lists the performance objectives for the advanced classification activities. These apply to the similar work performed using NRP demonstration area advanced classification data. Results evaluations are provided in the following sections.

Table 7-1. Performance Objectives and Results for Field Activities

Performance Objective	Metric	Success Criteria	Results
Repeatability of IVS measurements	Amplitude of EM anomaly Measured target locations	Adv. Sensors Survey: Down-track location ±25 cm Adv. Sensors Cued: Library match ≥90% using 3-criterion metric with equal weighting to the three criteria using first day's IVS inversion as the library item.	Fail – Two (2) IVS events exceeded the detection offset of <25 cm Fail – Only 87% of cued IVS events achieved a ≥90% library match using an equally weighted 3-criterion match Explanation provided in subsequent sections.
Complete coverage of the demonstration site	Footprint coverage calculated using UX-Process Footprint Coverage QC tool; excludes inaccessible areas.	>= 85% coverage at 0.50-m line spacing; and >= 98% coverage at 0.60-m line spacing	Pass – 93.8% coverage was achieved at a 0.50-m line spacing, 99.1% at 0.60 m line spacing
Along-line measurement spacing	Point-to-point spacing from data set	98% < 25-cm along-line spacing	Pass – 100% of the along-line spacing was <25 cm
Detection of all TOI	Percent detected of TOI	100% of TOI detected within 40-cm halo of the surveyed location	Pass – 100% of TOI was detected within a 40-cm halo
Cued interrogation of anomalies	Instrument position	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location	Fail – Only 94% of the cued measurements were within the 40-cm metric Explanation provided in subsequent sections.

Table 7-2. Performance Objectives and Results for Advanced Classification Activities

Performance Objective	Items	Metric	Success Criteria	Results
Correctly classify QC seeds and correctly classify native and population seed items	All seeds and all native TOI	Percent classified as TOI	100% classified as TOI	Pass – all TOI were properly classified
Correctly identify group	All TOI and all excavated Non TOI	Percent of TOI and excavated Non TOI grouped correctly	85% correctly grouped in the Small, Medium and Large groups	Pass – 98% were assigned to the correct group
Correct estimation of extrinsic target parameters	All excavated anomalies	Measured location and depth to center of mass of recovered items	X, Y < 15 cm (1σ) Z < 10 cm (1σ)	Pass– σ of X,Y offsets < 15 cm Pass– σ of Z <10 cm of the actual depth Explanation provided in subsequent sections.
Maximize correct classification of non-TOI	All non-TOI	Number of false alarms eliminated	Reduction of clutter digs by >50% while meeting all other demonstration objectives	Pass – 81% of non-TOI were correctly classified
Minimize number of anomalies that cannot be analyzed	All cued anomalies	Number of anomalies that must be classified as "Unable to Analyze"	Reliable target parameters can be estimated for > 95% of anomalies on each sensor's anomaly list.	Pass – only 2% classified as "Cannot Analyze"

7.1 OBJECTIVE: REPEATABILITY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS

7.1.1 Dynamic IVS

This objective involved the repeatability of the detection location of seed items in dynamic IVS data collection. Seed item offsets for each dynamic IVS data collection event were tracked throughout the life of the dynamic portion of the project. This objective was considered to be met if all locations of seed items as detected in the dynamic IVS data were offset <25 cm from the actual surveyed location. Results for dynamic detection IVS surveys are detailed in Table 7-3.

Table 7-3. IVS Seed Item Detection Results

Seed Item	Seed Type	Minimum Offset (cm)	Maximum Offset (cm)	Average Offset (cm)
IVS01	Small ISO40	0.06	0.20	0.14
IVS02	Small ISO40	0.02	0.18	0.10
IVS03	Small ISO40	0.16	0.27	0.23
IVS04	Medium ISO	0.07	0.20	0.12
IVS05	Medium ISO	0.16	0.26	0.20
IVS06	Medium ISO	0.02	0.16	0.08
IVS07	Large ISO	0.03	0.19	0.11
IVS08	Shotput	0.05	0.18	0.11

The 25cm metric was exceeded on 2 occasions; once at seed IVS03 and once at seed IVS05. The remainder of the detection offsets were all within 25 cm of the actual surveyed locations, however, as a result of the two exceedances, this objective was not met.

7.1.2 Cued IVS

This objective involved the repeatability of classification of IVS seed items during cued data collection. Seed item library match statistics for each cued IVS data collection event were tracked throughout the life of the cued portion of the project. This objective was considered to be met if the library match statistic for all seed items cued in the IVS was ≥90% when using a three-criterion metric with equal weighting to the three criteria when measured against the first day's cued IVS. Results for cued IVS surveys are detailed in Table 7-4.

This performance objective was not met, as not all of the library match statistics of the inverted data to the IVS seed item library were >90% during the duration of the cued survey.

The IVS results were monitored throughout the duration of the cued data collection, and data not meeting the performance objective were reviewed real-time in an attempt to determine the source of any noted failures. The exact source of the failures was not determined, however, a contributing factor is most likely the IVS construction or the seed items installed in the IVS. Due to limited suitable space available to install an IVS within the NRP area, the existing IVS established for the EM61-MK2 survey being performed in support of the clearance activities was used for the demonstration. Schedule 40 small ISOs were used in the IVS, which may have been a contributing factor to the inconsistent results of the deeper small ISO seed item IVS03. It is unclear what caused the match statistic deviations over the medium ISO seed items.

Table 7-4. IVS Library Match Results

Seed Item	Seed Type	Seed Depth (m)	Minimum Library Match Statistic	Average Library Match Statistic
IVS01	Small ISO40	0.10	0.97167	0.991439
IVS02	Small ISO40	0.10	0.9738	0.988419
IVS03	Small ISO40	0.23	0.861	0.94605
IVS04	Medium ISO	0.23	0.74866	0.886833
IVS05	Medium ISO	0.43	0.89001	0.924231
IVS06	Medium ISO	0.43	0.79654	0.875971
IVS07	Large ISO	0.44	0.95062	0.978406
IVS08	Shotput	0.30	0.97599	0.98819

To assess data usability, production data were evaluated from any day that IVS deviations were observed, and no indications of a system failure with respect to data usability were observed. Seed items cued during the days in question were properly classified with high confidence statistical matches, and no deficiencies were noted in sensor performance.

7.2 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

This objective measured the effectiveness of the dynamic detection survey as a function of the amount of coverage of the demonstration area by the TEMTADS 2x2 sensor. This objective was considered to be met if the dynamic detection survey achieved 85% coverage of the site at a 0.50-m lane spacing, and 98% of the site at 0.60-m lane spacing. The UX-Process Footprint Coverage QC tool was used to analyze the georeferenced positions of the center of the TEMTADS 2x2 sensor array. Data were collected at a 0.50m lane spacing to eliminate gaps caused by ruts and rough terrain. This objective was met, as 93.8% of the site was covered at a 0.50m lane spacing, and 99.1% at 0.60m lane spacing.

7.3 OBJECTIVE: ALONG-LINE MEASUREMENT SPACING

This objective evaluated the along-line data density, or sample separation, of the TEMTADS 2x2 dynamic detection dataset acquired within the NRP area. The metric for this objective was the point-to-point distance as measured using UX-Process Sample Separation utility. This objective was considered to be met if 98% of the data had an along-line spacing of 25 cm or less.

The UX-Process Sample Separation tool was used to analyze the along-line spacing of the georeferenced data positions of the TEMTADS 2x2 sensor array. This objective was met, because 100% of the data had a sample separation of 25 cm or less.

7.4 OBJECTIVE: DETECTION OF ALL TOI

This objective evaluated the dynamic detection capabilities of the TEMTADS 2x2 array. The metric for this objective was considered to be met if 100% of native and non-native TOI were detected within a 40-cm halo of their recorded locations. Non-native TOI within the TEMTADS 2x2 demonstration area included 13 blind seed items which were completely blind to the data collection and processing teams, as well as 6 QC seed items in which the locations were known.

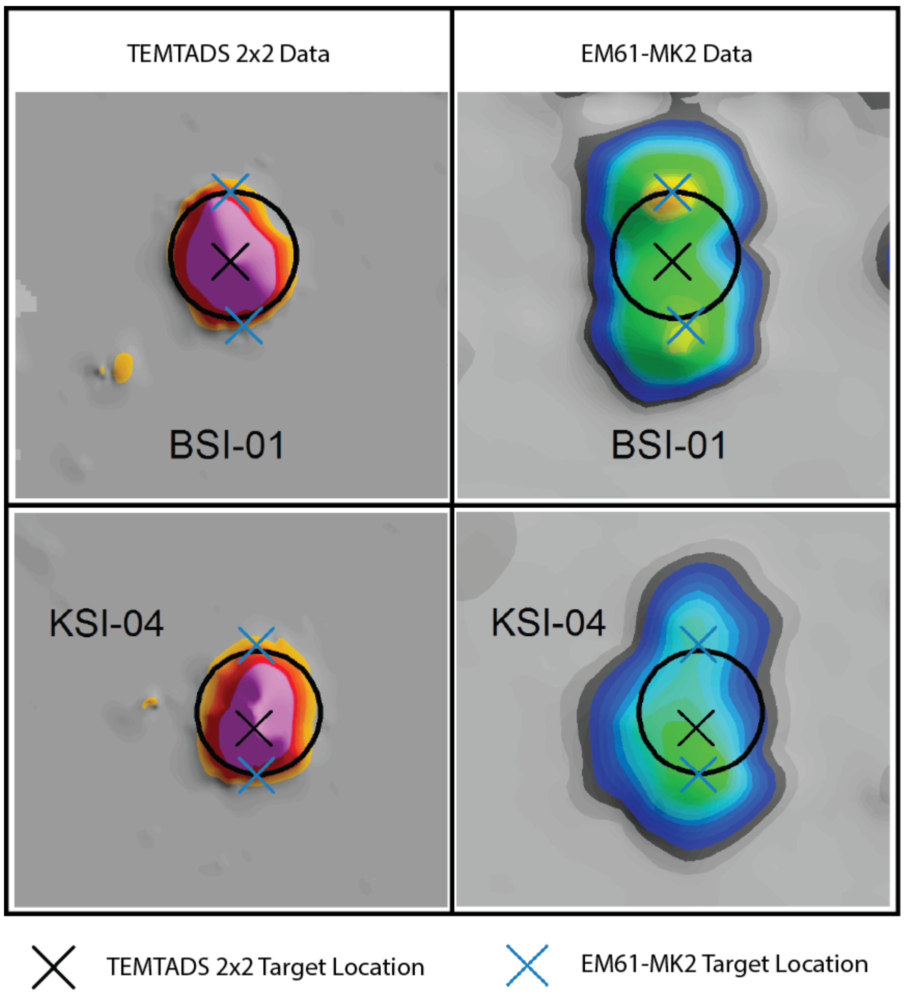
This objective was met, because all TOI were successfully detected within the TEMTADS 2x2 dataset within 40 cm of the recorded locations. TOI included 19 seed items (non-native TOI) installed by WESTON prior to the dynamic detection survey. TOI detection results are detailed in Table 7-5. For comparison, the offset from the existing EM61-MK2 datasets are also included in the table.

Table 7-5. TOI Detection Results

Seed ID	Seed Type	Seed Offset (cm)	
		TEMTADS 2x2	EM61-MK2
BSI-01	Small ISO80	5	47
BSI-02	Small ISO80	11	23
BSI-03	Small ISO80	25	32
BSI-04	Small ISO80	12	30
BSI-05	Small ISO80	14	24
BSI-06	Small ISO80	4	58
BSI-07	Small ISO80	16	45
BSI-13	Small ISO80	6	24
BSI-14	Small ISO80	6	18
BSI-15	Small ISO80	6	13
BSI-18	37mm	10	33
BSI-19	37mm	2	16
BSI-20	37mm	12	43
KSI-04	Small ISO80	11	47
KSI-05	Small ISO80	17	40
KSI-06	Small ISO80	17	41
KSI-07	Small ISO80	7	14
KSI-08	Small ISO80	11	45
KSI-09	Small ISO80	2	13

The average seed item offset for the TEMTADS 2x2 was 10.2cm, whereas the seed item offsets for the EM61-MK2 averaged 32cm. EM61-MK2 data were collected using a 2 ft. transect spacing, on average while TEMTADS 2x2 array data yield transect spacing of 40cm or less from sensor to sensor. These results suggest that the improved spatial resolution achieved by the TEMTADS 2x2 array of smaller footprint sensors leads to higher accuracy in detection of subsurface items of interest. Figure 7-1 shows two examples of seed items as detected by each sensor. The TEMTADS 2x2 location is shown as a black "x", whereas the EM61-MK2 detected locations are shown as a blue "x".

Figure 7-1. Comparison of TEMTADS 2x2 and EM61-MK2 Detection Performance



As detailed in Table 7-3, BSI-01 and KSI-04 had TEMTADS 2x2 detection offsets of 5cm and 11cm, respectively. These same seed items had EM61-MK2 detection offsets of 47cm in both cases. In both scenarios the EM61-MK2 data showed a double peak over the seed item, with the closest peak being at the 47cm offset distance. TEMTADS 2x2 displayed a single consolidated anomalous response in both cases. This is of importance, as each of the reacquired locations in both of these EM61-MK2 scenarios (two reacquired locations per seed item) will be greater than 40cm from the actual source location, and will result in a minimum of 3 cued field measurements

to adequately characterize the source (an initial measurement at each reacquired location, with at least one additional recollect from one of the locations based on the in-field inversion results). Conversely, the reacquired locations as detected by the TEMTADS 2x2 will most likely only require a single cued measurement.

7.5 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

This objective evaluated the positioning of the instrument during data collection in relation to the actual anomaly location. The metric for this objective was considered to be met if the center of the instrument was positioned within 40 cm of the actual anomaly location for 100% of the cued anomalies.

Comparison of TEMTADS 2x2 cued locations to the actual location of recovered items is not possible. Detailed intrusive information and locations of recovered items were not collected by the contractor performing the MEC removal activities.

As a result, this objective was evaluated by comparing the offset between the center of the TEMTADS 2x2 array and the fit location of each source. Of the 1,195 cued measurements that were analyzed, 1,127 were within the 40-cm offset metric, and 68 were outside of 40 cm. 39 of these exceedances were from the 977 targets (4% of TEMTADS targets) selected from dynamic TEMTADS 2x2 data, and 29 were from the 218 targets (13% of the EM61 targets) selected from EM61-MK2 data. The increased exceedance rate at targets selected from the lower resolution EM61-MK2 dynamic detection survey suggests that the data in which the target locations are selected from will influence failure rates. This objective was not achieved because only 94% of the cued measurements were within the 40-cm offset.

7.6 CORRECTLY CLASSIFY QC SEEDS AND CORRECTLY CLASSIFY NATIVE AND POPULATION SEED ITEMS

This objective evaluated the effectiveness of the advanced classification process to properly classify TOI present within the survey area. The objective was considered to be met if 100% of the QC seeds, population seeds, and native TOI were placed on the TOI list.

A ranked anomaly list was submitted to the ESTCP Program Office for evaluation. This objective was met, because all TOI were properly classified as category 1 digs (likely TOI).

7.7 OBJECTIVE: CORRECTLY IDENTIFY GROUP

This objective evaluated the effectiveness of the advanced classification process to properly assign each excavated TOI and non-TOI into the small, medium, or large grouping. The objective was considered to be met if 85% of the anomalies placed on the dig list were properly grouped.

Dig results for the ranked anomaly list submitted to the ESTCP Program Office were analyzed to verify size groupings. Intrusive investigations were performed to the specifications of the 3rd-party contractor's work plan, and did not follow the standard ESTCP intrusive investigation requirements, so dig data obtained did not include precise locations, depths, photos or descriptions of items recovered. Since precise data were not available, a qualitative analysis was performed on the dig results to determine if the proper group was assigned to each item. Of the 220 anomalies

placed on the dig list, 186 were assigned to the correct size group, 3 were assigned an incorrect group, and 31 did not have adequate data to make a comparison. This objective was met, as 98% of the anomalies that had adequate dig data for a qualitative comparison were correctly classified.

7.8 OBJECTIVE: CORRECT ESTIMATION OF EXTRINSIC TARGET PARAMETERS

This objective evaluated the accuracy of the target parameters that are estimated during the data inversion process by comparing the predicted extrinsic target parameters to the measured results recorded during the intrusive investigation. This objective was considered to be met if the estimated X and Y locations were within 15 cm and the estimated depths were within 10 cm.

Detailed locations and depths of items recovered were not recorded during the intrusive investigation, so a complete evaluation of all cued data could not be performed. Therefore, this objective was evaluated by comparing the fit locations derived from the cued TEMTADS data to the RTK surveyed locations and depths of the seed items installed within the TEMTADS demonstration area. Measured offsets for the X, Y and Z orientations, as well as the standard deviation of the offsets for each orientation are detailed in Table 7-6.

This objective was met, as the standard deviation for each of the X and Y horizontal offset and the Z vertical offset were <15 cm and <10 cm respectively.

7.9 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

This objective concerns the component of the classification problem that involves false alarm reduction. The metric for this objective is the number of cued anomalies that can be correctly classified as non-TOI. The objective was considered to be met if more than 50% of the non-TOI items were correctly labeled as non-TOI.

Dig results for the initial ranked anomaly list submitted to the ESTCP Program Office were used to assess the number of non-TOI that were correctly classified. Results are detailed in Table 7-6.

This objective was met, because 81% of non-TOI were correctly classified. In this classification scenario, 100% of TOI were correctly classified while achieving a false positive rate of only 18%. A Receiver Operating Curve (ROC) generated from the dig results of the submitted ranked anomaly list is shown in Figure 7-2.

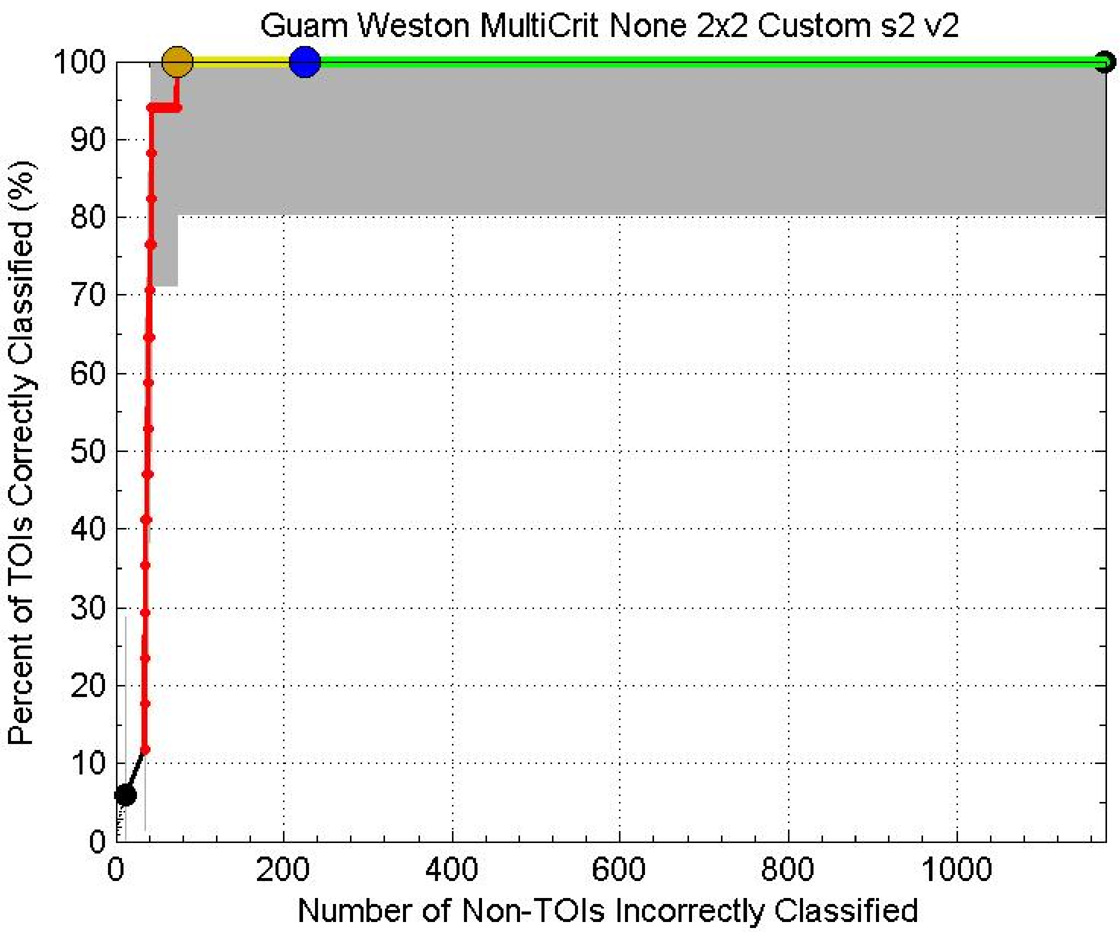
Table 7-6. Extrinsic Target Parameters

Seed ID	Seed Type	X Offset (cm)	Y Offset (cm)	Z Offset (cm)
BSI-02	Small ISO80	1.32	3.40	3.23
BSI-03	Small ISO80	16.46	3.45	6.35
BSI-04	Small ISO80	5.96	7.19	4.50
BSI-05	Small ISO80	10.10	0.95	0.97
BSI-07	Small ISO80	3.70	1.29	0.74
BSI-13	Small ISO80	0.20	3.63	5.74
BSI-14	Small ISO80	0.97	0.23	1.64
BSI-15	Small ISO80	2.71	7.66	0.70
BSI-16	37mm	2.86	5.53	1.73
BSI-18	37mm	2.48	1.14	5.32
BSI-19	37mm	6.07	0.12	6.32
BSI-20	37mm	9.18	7.64	12.57
KSI-02	Small ISO80	0.62	1.35	0.23
KSI-04	Small ISO80	3.46	0.64	1.29
KSI-05	Small ISO80	3.34	1.67	0.32
KSI-06	Small ISO80	0.60	6.74	0.17
KSI-07	Small ISO80	11.17	26.88	8.30
KSI-08	Small ISO80	9.00	2.10	1.13
KSI-09	Small ISO80	1.30	2.37	1.32
KSI-10	Small ISO80	1.81	2.44	2.03
Standard Deviation (σ)		4.40	5.87	3.30

Table 7-7. Predicted vs. Actual Classification Results

	Categorized TOI	Categorized Non-TOI
Predicted	243	952
Actual	19	1,176
% Correctly Classified	100%	81%

Figure 7-2. Guam NRP Area Final Receiver Operating Curve



7.10 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

This objective evaluated how well the modeled results of the inversion process correlated to the observed data. A fit coherence metric is calculated for each model during data inversion, and is used as the basis for determining whether reliable parameters could be estimated from the data. The objective was considered to be met if reliable parameters could be estimated for > 95% of the anomalies on each sensor anomaly list.

Modeled results with a fit coherence of less than 0.8 were placed in the 'cannot analyze' category. This objective was met, because 98% of the cued data collected inverted with a fit coherence greater than 0.8.

8. COST BENEFIT ANALYSIS

The cost assessment for the Andersen AFB demonstration at NRP area includes a summary list of the project costs and potential savings from the classification process.

8.1 COST MODEL

The costs for the NRP area field demonstration included the seeding, TEMTADS 2x2 surveys, and data processing. These costs are summarized in Table 8-1.

Table 8-1. Details of Project Costs

Phase of Work	Elements of Work	Estimated Costs
Mobilization/ Demobilization	Travel for a geophysicist and UXO technician and shipment of TEMTADS 2x2 and other equipment	\$16,000
Site Setup	Site prep, seeding, IVS installation, weather delays	\$15,000
Dynamic Detection Survey	Includes effort for field data collection (2.97 acres), equipment, expenses, labor for geophysicists and UXO technicians, processing/ anomaly selection, weather delays/ downtime and local subcontractor support (10 days)	\$34,000
	Total cost per acre for dynamic survey	\$11,447/ acre
Cued Survey	Equipment, data collection, labor for geophysicists and UXO technicians and expenses, weather delays/ downtime and local subcontractor support (5 days)	\$51,000
	Data processing and classification	\$34,000
	Total cost per anomaly for cued survey (1,195 anomalies)	\$71/anomaly

8.2 COST DRIVERS

This analysis presents and compares the costs of the dynamic and cued surveys to the outcome of the classification process. Due to logistical considerations with the location of Guam, travel (mobilization/ demobilization) as well as Site Setup has been separately reported in Table 8-1. WESTON also procured the help from a local subcontractor to provide additional UXO Technician escort and avoidance support, vehicles, storage and equipment. TEMTADS 2x2 shipping was approximately \$12,000. Expenses and some labor were expended during weather delays and downtime due to equipment issues.

A total of 2.97 acres of dynamic detection survey data was collected using TEMTADS 2x2 over the course of 5 days. The total cost for the dynamic detection survey was approximately \$34,000

equating to $11,447 per acre. The cued survey, data analysis and classification at 1,195 anomalies totaled $85,000 equating to $71 per anomaly.

WESTON considers the costs incurred for both the dynamic detection and cued surveys an overestimation of the actual costs that would be necessary for future projects because these costs included significant logistical considerations and a lengthy setup and orientation process. An average of 0.6 acres per day was achieved for dynamic detection surveys. A total of 1.6 acres per day was achieved when a full day of data collection was possible. An average of 120 anomalies per day was achieved during cued surveys. A total of 244 anomalies per day was achieved when a full day of data collection was possible.

8.3 COST BENEFIT

All anomalies were intrusively investigated as part of the MEC removal action.

The classification process eliminated 81% of anomalies that would be required to be intrusively investigated. A savings of $16,000 or 9% of the total cost would be saved based on the following assumptions and factors:

- The 1,195 anomalies spanned 4 acres.
- If a TEMTADS 2x2 dynamic detection survey was performed across the entire 4 acres of the NRP area the total survey cost would be $45,788.
- The total cost to classify all anomalies was $85,000.
- We assume the average wraparound cost of $150 per anomaly for the intrusive work the total cost for 1,195 anomalies would be $180,000.
- The classification process reduced the dig list to 243 anomalies from 1,195 anomalies.
- At $150 per anomaly, the total intrusive work would be $36,450 for 243 anomalies.
- By using geophysical classification process under these assumptions, the total MEC removal action cost is $167,238.
- Under this scenario, a savings of approximately $12,762 would be realized or 7% of the total cost without using geophysical classification.

9. IMPLEMENTATION ISSUES

The primary implementation issue observed during the demonstration at Guam was data collection delays due to minor inclement weather. The TEMTADS 2x2 system is not weather ruggedized, and as a result, cannot be used in even slightly adverse weather conditions (light rain, misting, etc…) without the possibility of moisture entering the sensor housing clamshell or computer backpack. Due to this, upwards of 10 field days were lost during the mobilization due to precipitation and moisture issues, or system downtime most likely caused by moisture infiltrating system components.

Minor setbacks also occurred during the project, such as software malfunctions, computer component failures, failed sensors, data collection delays due to extreme weather events (tropical storms, etc...). These types of setbacks can be typical of any site and should be expected when planning field operations.

Based on the data collection experience at Guam, the following suggestions were made for improvement of the system and sensor platform.

- **Weatherproof the system –** Limited protection of cables and electronics is built into the TEMTADS 2x2 system. The clamshell is not sealed to outside moisture and dust. Sensor failures, likely due to moisture entering the clamshell, resulted in several days of downtime and system troubleshooting. A rubber gasket sealing the top and bottom clamshell pieces, as well as the cable harness entering the clamshell, is a possible solution.
- **Wheels –** Currently the wheels are held on by zip ties, as opposed to nylon bolts or cotter pins. These zip ties routinely failed on almost a daily basis, leading to downtime to reattach wheels and recollect affected lines.
- **Other modifications –** Other modifications discussed included a modification of EM3Dacquire to allow for display of dynamic data collection progress (plot tracks on map, similar to the MetalMapper EM3D interface), and the option to import a flag/target list into TEMDatalogger to avoid operator input errors.

10. REFERENCES

1. Explosives Safety Submission – Guam Construction Support, Amendment #5, June 2012.

2. WESTON (Weston Solutions, Inc.). 2014. *ESTCP Munitions Response Live Site Demonstrations, Andersen Air Force Base, Guam, Demonstration Plan*. Prepared for Environmental Security Technology Certification Program. ESTCP Project Number MR-201231. January 2014.

Appendix A: Points of Contact

POINT OF CONTACT	ORGANIZATION	PHONE FAX EMAIL	ROLE IN PROJECT
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